# Upper ocean vertical supply: A neglected primary factor controlling the distribution of neodymium concentrations of open ocean surface waters?

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[1] Neodymium (Nd) isotopes are an important geochemical tool to trace the present and past water mass mixing as well as continental inputs. The distribution of Nd concentrations in open ocean surface waters (0–100 m) is generally assumed to be controlled by lateral mixing of Nd from coastal surface currents and by removal through reversible particle scavenging. However, using $^{228}$Ra activity as an indicator of coastal water mass influence, surface water Nd concentration data available on key oceanic transects as a whole do not support the above scenario. From a global compilation of available data, we find that more stratified regions are generally associated with low surface Nd concentrations. This implies that upper ocean vertical supply may be an as yet neglected primary factor in determining the basin-scale variations of surface water Nd concentrations. Similar to the mechanism of nutrients supply, it is likely that stratification inhibits vertical  yet yetto subsurface thermocline waters and thus the magnitude of Nd flux to the surface layer. Consistently, the estimated required input flux of Nd to the surface layer to maintain the observed concentrations could be nearly two orders of magnitudes larger than riverine/dust flux, and also larger than the model-based estimation on shelf-derived coastal flux. In addition, preliminary results from modeling experiments reveal that the input from shallow boundary sources, riverine input, and release from dust are actually not the primary factors controlling Nd concentrations most notably in the Pacific and Southern Ocean surface waters.

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## 1. Introduction

[2] The quasi-conservative isotopic composition of the rare earth element (REE) Nd in seawater is being widely used as a powerful tracer for modern and past water-mass mixing, as well as for continental inputs [e.g., *von Blanckenburg*, 1999; *Goldstein and Hemming*., 2003; *Peucker-Ehrenbrink et al*., 2010]. Although considerable efforts and progress have been made in the understanding of the modern marine Nd cycle in recent years [e.g., *Lacan and Jeandel*, 2005; *Arsouze et al*., 2007, 2009; *Jones et al*., 2008; *Siddall et al*., 2008; *Andersson et al*., 2008; *Porcelli et al*., 2009; *Oka et al*., 2009; *Amakawa et al*., 2009; *Rickli et al*., 2010; *Rempfer et al*., 2011; *Carter et al*., 2012; *Grasse et al*., 2012; *Stichel et al*., 2012; *Singh et al*., 2012; *Grenier et al*., 2013], some important issues, such as the nature

different factors that control variations of Nd concentration in open ocean surface waters (0–100 m, with bottom depth > 500 m).

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Given these sites are mostly close to continents, it is likely that they have been considerably influenced by coastal fluxes, for which it is well known that they are characterized by high $^{228}$Ra activities. These fundamental and systematic differences between Nd concentrations and $^{228}$Ra activities indicate that surface water Nd concentrations must also be influenced by processes other than the coastal influence and which did not exert primary control on $^{228}$Ra distribution. It is noteworthy that Nd concentrations in high-latitude surface waters of both hemispheres [*Siddall et al*., 2008] are actually not lower than in subtropical areas where particle export fluxes are lower. This characteristic challenges the role of particle concentration as the major controlling factor of the global distribution of surface water Nd concentrations. Instead, we suggest that flux of Nd from the subsurface waters is an important source of Nd to surface waters and thus an important mechanism for driving basin-scale variations of Nd concentrations in the surface ocean.

### 3.2. The Supply of Nd From Subsurface Thermocline Waters to the Surface Layer

[13] Because Nd behaves similar to nutrients as introduced in section 1, a potentially important issue is the mechanism by which nutrients are transferred from the subsurface thermocline waters to the euphotic layer at different latitudes, which is still subject of considerable biogeochemical debate both in observational and modeling studies [e.g., *Oschlies and Garcon*, 1998; *McGillicuddy et al*., 2007; *Sarmiento et al*., 2004; *Palter et al*., 2010].

[14] In high latitudes, where the surface ocean is generally less stratified than in low latitudes, nutrients are transferred from thermocline waters into the overlying deepened mixed layer by a combination of vertical and lateral advection (e.g., nutrient streams) [*Williams et al*., 2006; *Marshall and Speer*

*Arsouze et al*., 2009; *Rempfer et al*., 2011, 2012b] is an important, even overwhelming source of Nd to the global ocean. Since the exact nature of the boundary Nd source is still largely unknown, a precise estimation of shallow coastal Nd flux to the surface layer is difficult. Even if we assume that all the Nd from the boundary source (5.5 $10^9$ g Nd/yr following *Rempfer et al*. [2011]) is supplied to the ocean via the surface layer, the total external flux from dust, river, and boundary source (summing up to 6.1 $10^9$ g Nd/yr) only accounts for up to 37% of the required surface flux. Moreover, it is important to keep in mind that extremely high oceanic surface productivity normally occurs in the continental shelf areas [*Falkowski et al*., 1998]. It is thus likely that, due to the high particle concentration and associated scavenging on or near the shelves, a large fraction of shelf Nd cannot

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